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MECHANICAL PROPERTIES OF COLD-ROLLED COMMERCIALLY PURE TITANIUM SHEET, AMS 4901 (Ti-75A)

MRG-191

Prepared by: J.E. Chafey

GENERAL DYNAMICS/CONVAIR

CONVAIR ASTRONAUTICS

4 October 1960

SUBJECT: "Mechanical Properties of Cold-Rolled Commercially Pure Titanium Sheet, AMS 4901 (Ti-75A)"

ABSTRACT: Standard and notched tensile tests were conducted at +78°, -60°, -320°, and -423°F in both longitudinal and transverse directions on samples from a 0.012" thick sheet of AMS 4901 which had been cold rolled approximately 30%. The material exhibited promising properties at room temperature (120 ksi F_{ty}, 135-140 ksi F_{tu}, 5% elongation, and notched/unnotched tensile ratios in excess of unity); but tests at all sub-zero temperatures demonstrated notch sensitivity which increased with decreasing temperature.

While the strength of commercially pure titanium (AMS 4901) can be significantly increased by cold working, such material is not recommended for cryogenic temperature applications. It would be of interest to determine the low temperature properties of higher purity unalloyed titanium (AMS 4900 and AMS 4902) in the cold rolled condition.

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4 October 1960

TO: Distribution

FROM: Materials Research Group, 592-1

SUBJECT: Mechanical Properties of Cold-Rolled Commercially Pure Titanium Sheet, AMS 4901 (Ti-75A)

INTRODUCTION:

The applicability of certain titanium alloys for use in experimental thin-skinned tanks to contain cryogenic propellants is limited by the fact that these alloys cannot be commercially produced in gages below approximately 0.025" in thickness, whereas some projected tank designs consider the utilization of 0.010" gages. The 5Al-2.5 Sn-Ti alloy, for example, has been demonstrated to possess excellent combinations of strength, ductility, fracture resistance, and good welded joint properties at temperatures down to -423°F, but has been produced in thicknesses below approximately 0.020" only by chemical milling processes which often result in poor surface condition, poor thickness control, and may lead to hydrogen embrittlement.

Unalloyed titanium in the annealed condition has good ductility and impact resistance at extreme sub-zero temperatures[1] and can be rolled in wide sheet form down to foil gages. The Titanium Metals Corporation of America, suggested that cold-rolled-to-strength thin gage unalloyed titanium be evaluated for possible substitution for the 5Al-2.5 Sn-Ti alloy in cryogenic applications inasmuch as the strength of the latter alloy could be readily matched by cold working the unalloyed material, and furthermore, cold rolling of titanium sheet in the Sendzimir mill would develop superior surface condition and permit 1/2 AISI thickness tolerance control.

T.M.C.A. accordingly submitted a 0.012" thick sheet, 32" X 22" in size, which had been cold reduced from 0.017" (29.4% reduction), Heat No. M9656, AMS 4901, Ti-75A, commercial purity unalloyed titanium. The supplier furnished the following test data:

Longitudinal - F_{ty}-123.0 ksi, F_{tu}-143.0 ksi, Elongation -6%
Transverse - F_{ty}-124.0 ksi, F_{tu}-152.0 ksi, Elongation -6%

DATA AND DISCUSSION:

Standard and edge-notched tensile test specimens, CV-A drawings EMG-D-1 and MRG-D-10 respectively, were taken in both longitudinal and transverse directions and were tested at +78°, -60°, -320°, and -423°F. The small size

1. Memorandum on Mechanical Properties of Titanium and Other Materials at Very Low Temperatures" April 25, 1957, Titanium Metallurgical Laboratory, Battelle Memorial Institute.

of the sheet permitted no more than duplicate test specimens to be tested under any condition. The results of the tests are presented in Table I. Yield strengths were not determined at most of the sub-zero temperatures because of a malfunction of the extensometer.

The room temperature mechanical properties are somewhat lower than reported by the manufacturer but the strength is higher than usually obtained in the 5Al-2.5 Sn-Ti alloy and the ductility is lower. The notched/unnotched tensile ratio is in the range of 1.06-1.13, which, while above unity, is nevertheless below the level of 1.30-1.35 observed in the annealed 5Al-2.5 Sn-Ti alloy.

At sub-zero testing temperatures, the ductility decreases with decreasing temperature to values of 1.0-1.5% elongation at -423°F. The notched/unnotched tensile ratio, a much more meaningful criterion of brittle fracture susceptibility, decreases rapidly with decreasing temperature; being 0.95 at -60°F, 0.73 at -320°F, and 0.54 at -423°F in the longitudinal direction and lower in the transverse direction. Annealed 5Al-2.5 Sn-Ti alloy, 040" in thickness shows a notched/unnotched tensile ratio of 1.22 at -100°F, 1.15 at -320°F, and 0.97 at -423°F in the longitudinal direction, considerably higher values than obtained with the cold rolled unalloyed titanium sheet.

Based upon these results, cold rolled-to-strength unalloyed titanium sheet made to AMS 4901 cannot be recommended for cryogenic temperature applications because of its high notch sensitivity and tendency to brittle fracture at sub-zero temperatures.

Very high purity unalloyed titanium has a yield strength in the range of 10,000-20,000 psi. "Commercially pure" unalloyed titanium contains varying amounts of carbon, oxygen, iron, hydrogen and other impurities which increase its hardness and strength to considerably higher levels. "Commercially pure" unalloyed titanium is currently available in three grades as follows:

Grade Designation	AMS 4900	AMS 4901	AMS 4902
Minimum yield strength, psi	55,000	70,000	40,000
Carbon, Max. %	0.20	0.20	0.20
Hydrogen, Max. %	0.015	0.015	0.015
Other elements, total %	0.6	0.8	0.6

The AMS 4901 grade contains the highest level of total impurity content and has the highest strength of the three grades of unalloyed titanium. While the impurities increase the strength of titanium, they also decrease the ductility and increase the tendency toward brittle fracture, and this effect becomes more pronounced at lower testing temperatures. It would be of interest to evaluate the properties of cold rolled-to-strength AMS 4900 and AMS 4902 at sub-zero temperatures. The lower impurity contents of these materials may enhance their resistance to brittle fracture at sub-zero temperatures.

CONCLUSION:

1. 30% cold rolled unalloyed titanium (AMS 4901) sheet has promising room temperature mechanical properties, but demonstrates notch sensitivity which increases with decreasing temperatures in the range of -60° to -423°F.

2. Cold rolled-to-strength unalloyed titanium (AMS 4901) is not recommended for cryogenic temperature applications.

3. It would be of interest to evaluate the sub-zerotemperature mechanical properties of higher purity cold rolled-to-strength unalloyed titanium sheet (AMS 4900 and AMS 4902).

TABLE I

Mechanical Properties of Cold Rolled Commercially Pure Titanium Alloy Sheet
AMS 4901, TMCA Heat No. 9656 Cold Rolled 29.4% to 0.012" Thickness

TEST TEMP. °F	GRAIN DIRECTIONS	YIELD STRENGTH ksi	ULTIMATE TENSILE ksi	ELONG. %	NOTCHED TENSILE STRENGTH K_t=6.3 ksi	NOTCHED/ UNNOTCHED TENSILE RATIO
+78	Longitudinal	120.6	137.8	5.2	149.1	
	Longitudinal	120.7	136.6	5.2	140.9	
	Ave.	120.6	137.2	5.2	145.0	1.06
+78	Transverse	121.7	144.5	5.5	165.4	
	Transverse	121.6	147.4	5.2	163.4	
	Ave.	121.6	146.0	5.3	164.4	1.13
-60	Longitudinal	—	153.7	-	145.3	
	Longitudinal				147.4	
	Ave.				146.3	0.95
-60	Transverse	—	171.0	-	117.4	
	Transverse		172.3			
	Ave.		171.7			0.68
-320	Longitudinal	—	210.6	5.0	150.8	
	Longitudinal		212.3	5.5	155.4	
	Ave.		211.5	5.3	153.1	0.73
-320	Transverse	—	210.3	2.5	122.4	
	Transverse		212.3	2.5	136.8	
	Ave.		211.3	2.5	129.6	0.61
-423	Longitudinal	217.1	233.1	1.5	128.0	
	Longitudinal	—	240.5	-	129.9	
	Longitudinal	—	228.0	-	122.0	
	Ave.		233.9		126.6	0.54
-423	Transverse	—	237.4	1.0	121.2	
	Transverse	—	241.1	1.0	124.6	
	Ave.		239.2	1.0	122.9	0.51

TO: Distribution

FROM: Materials Research Group, 592-1

SUBJECT: Addendum I - MRG-191 "Mechanical Properties of Commercially Pure Titanium Sheet, AMS 4901 (Ti-75A)"

Tensile Test of Welded-Joint on 38" Specimen

Subsequent to the date that the notched and unnotched tensile test data for the subject material was summarized, as shown in Table I, one additional test was conducted on this sheet. This consisted of a static tensile test at room temperature on a welded-joint specimen conforming to CV-A Drawing No. 7-07781-823. The specimen width was 3.50" in the 16" long test section. The overall length of the specimen was 38". The joint was located at the center of the specimen and consisted of a Heliarc fusion butt weld plus a spot welded doubler of the same 0.012" thick cold-rolled titanium sheet. The doubler was attached by four rows of resistance spot welds on each side of the butt weld. The butt weld was roll-planished prior to attaching the doubler. The rolling direction of the sheet was parallel to the testing direction for both the specimens and the doubler. The material available was sufficient to prepare only one specimen.

The ultimate strength of the specimen, as determined by a static tensile test at +78°F, was 131,500 psi. Fracture occurred immediately adjacent to the fourth row of spot welds.

As noted in Table I, the ultimate strength of the unwelded sheet in the longitudinal direction was 137,200 psi, average. Hence, the joint efficiency on the basis of the test performed is 131,500/137,200 X 100 = 96%.

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